PROGRESS REPORT
(DELIVERABLE ITEM 0001AB)

FOR

BMDO SBIR PHASE I CONTRACT
#N00014-93-C-0182

TO

ANALYTICON CORPORATION

ON TOPIC OF

ENHANCED VEHICLE & EVENT TYPING SOFTWARE

12/03/93

I. INTRODUCTION

This mid-term report documents Analyticon Corporation's progress on the Phase I SBIR contract on the topic of "Vehicle & Event Typing Software".

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II. EXECUTIVE SUMMARY

II.1 SYNOPSIS / INTRODUCTION FOR PHASE I EFFORT

ABSTRACT

Analyticon's Phase I SBIR effort emphasizes real-time typing of strategic military booster threats (ICBMs & SLBMs) from satellite-based infrared sensor measurements of received radiant intensity from their boost phase rockets. It is crucial to BMC3 planning and commanding of assets for strategic missile defense via boost-phase target interception and for TMD, BMD ground resources (sensor, weaponry) utilization, and early warning (EW) of threats. Accordingly it necessitates properly understanding salient analytical foundations, automating candidate algorithm concepts, and resolving key algorithm - implementation issues. The upshot is an upgraded largely radiometric typing procedure couched entirely in sensor (i.e. focal plane) coordinates, that obviates reliance on formal launch point estimation information, readily uses target motion and all intensity measurements, and expediently combines / amplifies available multi-color data.

Our baseline typer entails judicious variants, configured per selected performance criteria / payoffs and input data pre-conditioning, of a decision-making process commonly known as a Fisher technique of cluster analysis for ascertaining the best decision space (i.e. coordinates of a measurement hyperspace), that is combined with a general Likelihood Ratio Test (LRT) of hypotheses testing for the accompanying decision rule (i.e. classification strategy).

We are also studying two alternative schemes that are innovative (and especially substantially so for the second not related to Fisher concepts), and should yield quicker typing information, key to BMDO's interests in intercepting threats before they might deploy warheads / dummies, or in typing Scud variants

or other relatively dim TBMs from fleeting / occluded glances, and refined typing by booster mod. In contrast it doesn't need a higher-dimension non-orthogonal decision space, and facilitates directly using multi-color real data in a different albeit viable / amplified way.

Our typing logic is distinguished from earlier work by its **primary and proper use of radiant intensity information.** This contrasts to merely "typing-by-origin" as commonly done throughout the "community" - that relies on accurate launch point estimation correlated with IN data on site content, and is thus is innately inadequate for scenarios such as comprised of mobile missiles or large type mixes at a site, and another related investigation. We want to supply more accurate time-urgent typing to BMDO users as opposed to relaxed IN needs. Our investigation is characterized by completeness, fidelity of algorithms / codes used, treatment of key analytical insight / issues for the problem, and **intended quantified solution of a major confused ID problem that confronts the satellite surveillance / tracking "community".**

Our techniques apply to varied DOD topics of discriminating reentry vehicles from decoys, aircraft or tank typing, nuclear event type confirmation, and discerning underground nudet tests from quakes. There are also several important societal - commercial payoffs in product / body sorting, defect detection, and robotics pattern following.

II.2 GENERAL STATUS OF PHASE I EFFORT

INTRODUCTION

This report section summarizes the work performed up to date, and the planned activities to be carried out by Analyticon to the end of this contract to demonstrate that timely typing of strategic and tactical missiles can be accomplished and provided to the BMC^3 element of a BMD system to support efficient utilization of weapon resources during strategic and theatre operations.

Accordingly Analyticon has developed two approaches for technical evaluation: (1) the baseline approach which was documented concisely in our proposal and uses primarily radiometric information, and (2) an alternative method that utilizes both metrics and radiometrics (noting that the conventional metric procedure, typing-by-origin [TBO, that is used in the operational EW system and touted generally for replacement systems] uses metrics mainly albeit some radiometric data factored per initial intensity reasonableness and rough gating logic).

The key salient features of Analyticon's typing procedures are as follows:

(1) The process is conducted in a sensor system of coordinates;

(2) Radiometric measurements (in two colors) or radiometric measurements & target motion are used as input data;

(3) Knowledge of booster launch point is de-emphasized as the key data for typing; and

(4) Typing of missiles providing only slightly different sensor measurements can be potentially accomplished.

MAJOR ACCOMPLISHMENTS

Analyticon has accomplished the following progress since the initiation of our SBIR Phase I study.

Requirements Development

Analyticon has developed a list of typing requirements that should be completed and coordinated with the BMD community. With this objective in mind and with the purpose of receiving feedback on our study plan and algorithm requirements, we contacted (and at his request) sent information to LTC Joseph Townsend of BMDO / GSI at the Pentagon. The information package (see Figures 1 - 6) showed the rationale for our work, objectives, preliminary performance requirements that a typing algorithm should meet (TBS values therein), scope of effort, approach, comparison between presently used algorithms and Analyticon approaches, and project schedule. We also requested that a meeting be coordinated by LTC Townsend to present our ideas to the BMD community (i.e. government personnel and even supporting FCRC - SETA staff if needed).

Proof-of-Concept Planning Change

Analyticon has made a major change to the proposed approach to demonstrate the typing algorithm performance. In the original proposal the proof-of-concept was implicitly based on simulated data (no GFI requested). Analyticon and its SBIR project Technical Monitor, Dr. Keith Bromley, realized that this approach was not conclusive, and could leave the door open to doubts about the capability of the proposed "enhanced" algorithms. Analyticon has thus **changed the algorithm validation approach, and will instead use real data collected by the present Early Warning (EW) satellite surveillance system.**

With that purpose we have contacted and had meetings with Tom Stocker of The Aerospace Corporation (in El Segundo) and with Rick Gamble and Charles Limbaugh of Sverdrup Corporation (operators of SDI Plume Data Center [PDC] at AEDC in Tennessee). We met Rick and "Chad" locally and followed-up with a trip to the PDC. While at AEDC we requested a consistent set of data for the observing

Figure 1

OBJECTIVE

- USING PRESENT & PLANNED SPACE-BASED EO SENSORS - PROVIDE MISSILE TYPING FROM MEASUREMENTS COLLECTED DURING BOOST PHASE
- TYPE TIMELY / ACCURATELY TO SUPPORT INTERCEPTION
  - BY BOOST PHASE MISSILE DEFENSE WEAPONS IN SUPPORT OF STRATEGIC MISSILE DEFENSE OPERATION
  - BY TACTICAL MISSILE DEFENSE WEAPONS IN SUPPORT OF THEATRE OPERATIONS

Figure 2

RATIONALE

- ADDED / PRIMARY VALUE OF ENHANCED BOOSTER TYPING FOR BMD
  - ENABLE TIMELY BOOST PHASE INTERCEPT BY STRATEGIC DEFENSE WEAPONS (BEFORE WARHEAD & PENAID TRAFFIC)
  - PROVIDE TIME-URGENT TACTICAL THREAT INFORMATION TO TMD ELEMENTS / USERS
- ADDITIONAL BENEFITS
  - ENHANCE TYPING OF PRESENT EARLY WARNING (EW) SYSTEM
    - MOBILE LAND-BASED BOOSTERS
    - FIXED / MIXED ARSENALS
    - CERTAIN LONG-RANGE LIQUID SLBMs
    - MOBILE SEA-LAUNCHED 2-3 PARTY ID QUANDARIES
  - SUPPORT BMC3 TO PRIORITIZE TRACKING & DEFENSE OF BOOSTERS WITH MULTIPLE-WARHEADS (IDENTIFY MODS WITH SINGLE VERSUS MULTIPLE WARHEADS)
  - ASSIST TRACKING
    - TRACK ASSEMBLY (GATES, ALSO PROFILE ACCESS IF USED)
    - MITIGATE FALSE & MISSED TRACKS

Figure 3

PRELIMINARY REQUIREMENTS

- THE TYPING FUNCTION SHALL SATISFY THE FOLLOWING REQUIREMENTS
  - TIMING REQUIREMENT
    - $<$ TBS SECONDS AFTER FIRST DETECTION FOR STRATEGIC MISSILE DEFENSE
    - $<$ TBS SECONDS AFTER BOOSTER BURN-OUT FOR THEATRE MISSILE DEFENSE
  - TYPING ACCURACY
    - TBD
  - PROCESSING
    - THE ALGORITHMS SHALL BE DESIGNED TO PROVIDE TYPING WITHOUT USING LAUNCH POINT LOCATION

Figure 4

APPROACH

- DEVELOP DERIVED REQUIREMENTS
  - COORDINATES USED
  - AMOUNT OF INFORMATION
- CONCEPTUALIZE SOLUTIONS (2 CANDIDATES)
  - PROPOSED TYPING TECHNIQUE (BASELINE)
    - HYPOTHESES TESTING IN HYBRID RADIOMETRIC - METRIC ALGORITHM PER
      - ✓ MODIFIED FISHER-LIKE DECISION COORDINATES
      - ✓ LIKELIHOOD RATIO TEST (LRT) FOR DECISION RULE
  - ALTERNATIVE TECHNIQUE
    - BASED ON FIRST & SECOND MOMENTS OF INTENSITY SIGNATURES AND TARGET MOTION IN FOCAL PLANE COORDINATES (AMPLIFIES SMALL VARIATIONS)
    - DECISION PER LRT
- DEVELOP, IMPLEMENT & CHECK-OUT SIMULATED LOGIC
- ANALYZE RESULTS & FORMULATION / IMPLEMENTATION ISSUES
- DOCUMENT FINDINGS

Figure 5

TYPING METHODS COMPARISON

TYPER	CRITERIA MAIN	CRITERIA SECONDARY	DATA NEEDS	PERFORMANCE TIME	PERFORMANCE ACC
Present (EW)	Launch Site	Intensity Region	Site Content Signatures Estimated Launch Point (from Sensor Track)	TBS	TBS
Proposed	Hybrid Radiometric/ Metric	Region	Signatures & Variations Target Track in Sensor Frame	TBS	TBS

PROPOSED APPROACH ADVANTAGES
- Does not require knowledge of launch point / contents
- Permits typing of confusing classes
- Enables typing to refined mission level (mods, range, ..)
- Enhances the usage of two colors
- Requires fewer looks

Figure 6

REVISED PLAN

- PHASE I
  - ASCERTAIN AND TALK TO CUSTOMER (LEARN SOFTWARE CAPABILITY / NEEDS, ESTABLISH PHASE II RAPPORT)
  - PRELIMINARILY DESIGN & ESTABLISH FEASIBILITY OF ENHANCED TYPING ALGORITHM AND SOFTWARE
  - CODE, IMPLEMENT & TEST ON PC (FORTRAN)
  - USE REAL / OFFICIAL DSP DATA (VERSUS SYNTHETIC REPRESENTATIVE IN-HOUSE DATA) TO AFFIRM EFFICIENT TYPER AS GOAL, STRIVING TO SOLVE KEY ID PROBLEM
  - INCORPORATE CUSTOMER FEEDBACK
- PHASE II
  - REFINE & STREAMLINE ALGORITHMS / SOFTWARE
  - IN-DEPTH PERFORMANCE EVALUATION
    - CONTINUE IF NEEDED RISKY USE OF REAL OFFICIAL DATA; TRY TO SOLVE OTHER KEY ID PROBLEMS
    - EMPHASIZE CUSTOMER'S INTERESTS & DATA
    - MAINLY MILITARY BUT SOME SOCIETAL PROBLEMS
  - FORMALLY TEST, DOCUMENT & DELIVER S/W TOOL
  - DEMOS & INTEGRATION
    - COMPARE / ASSIMILATE OTHER S/W OR TEST CASES
    - MODIFY FOR OTHER TARGET PROCESSORS & LANGUAGES
  - RECOMMEND OPS FORMS AND FURTHER R&D

satellite posts, estimated paths of viewed boosters, and associated real IR intensity observations - for specific booster types, that have engendered considerable identification confusion (with conventional metric TBO method) within the "community". We recently received such data (that is sufficiently extensive for at least two of the three requested groups of confused types).

Computer Program Development

Analyticon is developing two types of computer codes for booster typing. The first type of program will provide analysis data for choosing, between the two competing candidate procedures, the one that has maximal technical potential.

The second type of computer program is to be used for proof of the typing algorithm concept and its presumed enhancement. The algorithm and logic for processing the sensor measurements and generating the output (probable type and related confidence level) of the selected approach will be fully coded.

Analysis Computer Program Development

Analyticon has developed algorithms and is in the process of coding these algorithms to determine how the booster target will move on a space-borne IR surveillance sensor, in its sensor system of coordinates, if the boosters (for which data are provided) are hypothetically launched at various launch azimuths. This work is key and needed to complete the formulation selection task indicated below under future activities.

Proof-of Concept Computer Program Development

Analyticon is also in the process of developing a code that will permit the utilization of real data instead of simulated data for validation of our typing approaches.

Algorithm Development

Analyticon has developed all algorithms supporting the baseline and alternative typing approaches. We will evaluate them, and will modify the formulations, if needed, based on analyses to be carried out before finalizing the proof-of-concept computer program development.

FUTURE ACTIVITIES

Requirements Definition

Analyticon expects that the preliminary requirements (enclosed in package sent to LTC Townsend; tacitly assuming explicit spec request at meeting of interested parties) will be validated by BMDO by TBD. If this date is beyond Phase I, Analyticon will instead make TBS "educated guesses" and work toward satisfying them.

Formulation Selection

Analyticon is planning to complete a coarse evaluation of the two typing approaches by 12/17/93. At this time the approach selected for further in-depth study will be definitized.

Computer Program Development

The computer programming of the selected approach is planned to be completed and checked out by 1/15/94.

Demonstrate Proof-of-Concept

PC computer runs demonstrating the performance using real data is planned for completion by 1/25/94.

Documentation

Analyticon will document the algorithms, algorithm tradeoffs, proof-of-concept computer program (PC object code in Fortran), and results obtained during the proof-of-concept demonstration (versus said performance requirements). The Final Report will include this documentation, prepared per mandated ANSI standard of our SBIR contract (#Z39-18). It will be delivered by 1/31/94, unless a waiver of this due date is requested and granted (per no cost extension [per prior discussions / memo with ONR PCO and Technical Monitor], if unforeseen difficulties encountered in meeting aforementioned schedule dates - since we were contractually given only 19 instead of proposed 26 weeks to complete our SBIR Phase I project, another deliverable added, a revised plan adopted per Technical Monitor request, and "GFI" data issues).

II.3 DISCUSSION OF PHASE I EFFORT / STATUS TO DATE

TECHNICAL EFFORT ON BASELINE

Our baseline algorithm for booster typing entails an expedient variant of a *common* signature-analysis technique, largely originated by R. Fisher*, for determining the best decision-making

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* as a prelude to his documented findings on classifying flowers (versus bone sorting as commonly misunderstood, see 1936 taxonomy article of Reference 3 and corroboration in Reference 10); noting that he also discovered the Maximum Likelihood Filter (see 1912 article) of statistical estimation theory analogous to the LRT

coordinates followed by a statistically-compatible typing strategy that is tantamount to the best decision rule.

So far we have been able to largely formulate, computerize and check-out the key modules comprising our baseline approach:

- o utility routines for
  - o eigenvector / eigenvalue problem solution (both for symmetric matrices [as resultant for criteria of pre-conditioned norm of scatter ratio matrix SRM] and for non-symmetric forms of SRM [maybe surpisingly so though to some since SRM is product of symmetric matrices W^{-1} & B but the product constituents don't commute] which thus necessitates extra calculations that are not needed with norm of SRM payoff)
  - o matrix and vector manipulations
  - o random correlated noise generation

- o signature data reading and statistics formation (preliminarily albeit 2 issues involving obtaining sufficient data for the booster type / mods pertaining to the problem, of the three confused ID problems treated, of preliminarily prime interest to us, and of validating associated booster position data for handling all three problems), and related plotting routines

- o basic framework of methodology (tool user queries / nominal data overrides, measurement hyperspace determination, decision space and rule formation, hypotheses testing, ...)

We have also derived the equations for

- o adaptively mapping the signatures statistics or intensity observations from one scene to another (such as from test scenario, for which know historical signature data, to operational booster launching scenario, with choice dependent upon TBS considerations, without directly knowing / using the missile launch heading estimate to ascertain the aspect angle dependency)

- o two expedient algorithm alternatives that preliminarily seem so promising in achieving faster typing messages and handling $\geq$ 2 colors in an amplified way with simpler logic

Lastly, we have preliminarily qualitatively analyzed, with some quantification, all of the delineated issues on algorithm formulation and implementation (plus a couple extra ones, see Figure 7 below).

The interested reader is referred to the Appendix for more information on the baseline technique and typing in general, as couched in notions of modern pattern recognition.

Figure 7

TECHNICAL ISSUES

- MAP STATISTICAL MOMENTS OF SIGNATURE UNCERTAINTIES TO DISCRIMINATION SPACE
- MOMENT QUANTIFICATION
- ACCOMODATE SENSOR SATURATION / CLIPPING OF RECEIVED SIGNATURES
- MIS-MODELING EFFECT (GAUSSIAN ASSUMPTION IN HYPERSPACE, MONTE CARLO SAMPLING OF MOMENTS)
- OBSERVATION NOISE EFFECT
- MULTI-COLOR DATA USAGE RAMIFICATIONS
- OPTIMIZATION CRITERION IMPORT
- MULTI-CLASS VS REPEATED BINARY HYOTHESES TESTING

TECHNICAL ACCOMPLISHMENTS ON ALTERNATIVE METHOD

As stated in Section II.2 (Major Accomplishments), Analyticon has developed the equations to be used in the two computer programs to perform booster typing using primarily IR radiometric measurements (our proposal baseline) and, for the second, using radiometric and metric information (per somewhat an even emphasis on each form of information).

The basics of our typing concepts entail using templates which will be generated from the empirical data provided to Analyticon by Sverdrup / PDC. A preliminary set of these data has been received by us on 11/23/93, although there are still the two aforementioned salient issues to be resolved.

Algorithms

The typing approaches, and therefore also the templates developed by Analyticon to implement these typing approaches, are based not on the full time history of the measurements (up to the last look past launch) but on the mean value of the measurements and the square of the sum of the differences between the measurements and their calulated mean value - evaluated at a suitable data cutoff point for satisfying the typing message release time "spec". These values, which are unique for each missile type, are calculated for various elevation angles of the looks (so in sensor coordinates) and for several number of samples, for several simply-deduced approximate launch azimuths (i.e. heading), and for several times at which the first measurement is made from the time of booster liftoff.

Functionally the mean and mean squared values can be written respectively as

M = F(elevation, time from liftoff, heading, number of samples, missile type / mod)

MSV = G(elevation, time from liftoff, heading, number of samples, missile type / mod)

The functions F and G are obtained by fitting polynomials to the empirical data.

Ops Concept for Typing

Operationally the typing process will be as follows:

- After track initiation and track assembly is completed, the data processor will calculate, from the sampled sensor measurements, the mean and mean square values of the needed boost event data. Based on look elevation and azimuth angles, the geographical area (i.e. country or sea of origin for radiated / sensed IR energy source) will be identified.

- o The list of boosters and corresponding templates will be requested by the operational software from the database which contains boosters versus geographical area.

- o Two tests will be conducted in sequence. The first (coarse) test will be based on intensity measurements thresholds. It is expected that this test will reduce the candidate list of boosters. The second (fine) test will consist of testing each of the remaining candidate missile templates (via mean and mean square) to find the one that best fits the computed mean and mean square values derived from the satellite measurements of the viewed booster. To do so we must find the value of the time from launch and the launch heading (from North) that minimizes the difference between the template mean and mean square values and the sample mean and mean square (per IR observations of booster).

- o The probability that the IR returns belong to each of the considered missile types is calculated, on the basis of a Likelihood Ratio Test (LRT) or another suitable Bayesian decision criterion, and the most probable booster type is reported.

DETAILS ON PROGRAMMATIC EFFORT

On the interface front, we did the following:

- o kept our technical monitor abreast of key developments or needs (with appropriate phone calls and memos [dated 9/22, 10/5 & 10/11/93] with programmatic - technical comments and requests)

- o took a trip to the SDI PDC on 10/22/93 to meet the PDC personnel, see their facility / capability, chat with them concerning mutual needs / concerns, and request unclassified data needed for our investigation*

- o called various contacts at BMDO (notably LTC Townsend and CDR Upchurch in GIS Systems Engineering directorate) and even locally in BE program office at SMC (Lt Coleman) to apprise them of our ongoing investigation and inquire about their

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* a consistent adequately-sized set of information entailing DSP real data extracted from the ITEDB database for 3 identified groupings of boosters that are commonly confused in the so-called "community" (i.e. TBS types), with concomitant viewing satellite locations, and precise trajectories for the boosters seen - with sampling large enough to accurately characterize the sufficient statistics characterizing the signature variations over the sundry conditions causing the dispersions (influences of path, weather / environment, aspect, etc)

interest in our effort (and in the case of LTC Townsend and CDR Upchurch, who preliminarily expressed opinion that likely interest in various BMDO offices and would set up related meeting if we'd send information in writing corresponding to that J. Wagner mentioned over phone, we then followed up with an informative package for them to peruse and distribute appropriately so that we can firm our intent / plans on visiting [or meeting them here] and briefing them on our plans, techniques, and status*)

o had stimulating conversations with the local experts on DSP targets and background (notably Tom Stocker at Aerospace who is also the source of the ITEDB DSP database also distributed to the PDC, from which selected data subsets were recently accumulated, packed on floppies, and sent to us by our PDC contact - also with data format and other helpful information for our understanding / usage)

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* However, the latest feedback from LTC Townsend & CDR Upchurch indicates a stat-of-flux in strategic mission oriented directorates (for program funding-merging-transfer / staffing) so they suggested that we instead "smartly" contact the TMD sensors directorate (GTS, in particular Dr. Paul Temple therein, that needs typing advancements and could conceivably finance a follow-on activity) or (implicitly) wait awhile for a upcoming extensive reorganization of the strategic mission personnel.

APPENDIX — TECHNICAL DETAILS

REVISED PLAN

We proposed quantifying algorithm performance and issue resolution during Phase I implicitly via a suitably parameterized "gedanken experiment" (i.e. as a thought experiment to isolate performance "breakpionts" by selectively varying the signature overlap [didn't request GFI]). Accordingly we were going to use representative measurement data derived from an existent Analyticon computerized scene generator of sensor tracks for missile raids / "singles", that simulates the flight of arbitrary boosters via path profiles and that generates corresponding noisy azimuthal & elevation observations from viewing satellite sensors, and also generates concomitant IR intensity source signatures again from tabular input data. To this computational framework which we were going to add needed provisions for transforming the booster emitted radiant intensities to intensities received at the IR satellite sensor via influence parameters such as range, aspect angle, Earth central angle [indicative of atmospheric path attenuation], sensor responsivity and aperture - but preliminary disregard, except via arbitrary parameterizations of resultant effect, the influence of weather / environmental factors such as cloud cover, humidity, as well as booster type dependent values of plume shape and "optical thickness" that alter the signal.

However, at the urging of our Technical Monitor (i.e. Scientific Officer), Dr. Keith Bromley, we mutually agreed that we should strive, as a GOAL, to use real official data instead of suitably parameterized synthetic albeit "representative" data that we have in-house or could readily concoct. Keith reasoned convincingly that our focus should be on establishing rapport with "potential BMDO sponsors" of a follow-on Phase II effort and winning it, and that not using "blessed real data", such as from DSP, might harm our chances for continuation. Furthermore, he emphasized that we should endeavor to ascertain such interested / potential sponsors.

This data accordingly has been just supplied to us by the SDI Plume Data Center (PDC) at Arnold AFB (main contact is Rick Gamble of Sverdrup; noting incidentally that the PDC boss for Sverdrup, the PDC facility operator, was preliminarily identified to us as our main interface contact by Keith per feedback from Carl Nelson, the BMDO SBIR coordinator) as selected subsets of the so-called ITEDB database for DSP sightings in real-time (information distribution coordinated by Thomas Stocker of Aerospace). After valuable / stimulating converations that we had with Tom, we decided furthermore to concentrate, again as a GOAL, on trying to use real DSP data to validate our approach. We unilaterally said that we would also strive to solve at least one booster typing problem that has troubled the "community".

Resolution of this problem thus is paramount to the amount of signature data and applicable booster types and scenes (satellite post and booster path) that we requested and just received from the PDC. Lastly, note that our revised technical approach (see Figure 6) is thus risky schedule-wise but presumably justified by the value of our effort (in actually using real data to verify our software tool, establishment of related design / performance tradeoffs, and hopeful contribution to solving at least one key confused booster ID problem confronting the "community") and, of course, the payoff if our effort is continued in a second phase.

General Theory

We are keen on using radiometric observations more in order to enhance the capability to classify viewed object in real time. This is basically since conventional methods are limited in performance for tougher scenarios (fortunately not seen ops) or entail non-realistic hardware implementations (such as large staring mosaic sensor arrays) to provide the requisite discriminants as presently configured. For example, TBO and identification on the basis of staging times and propulsion parameters or even color ratios are limited in effectiveness or technical validity due to modeling and data issues.

In using intensity measurements one is naturally, but not necessarily, led to classical problem formulations and solutions of statistical decision theory. Accordingly it is desirable to ascertain the best coordinates and rule in the decision-making process. General notions on typing and the choices for decision coordinates and rule are shown below in Figures 8-10. The interested reader is referred to fine recent texts listed herein especially References 2 and 11.

Typical / Candidate Methods / Discriminants Used

Typing an observed booster's identity is usually done with metric means, so-called typing-by-origin (TBO). Accordingly TBO logic is only secondarily reliant on radiometric measurements, of the radiant intensity of the booster received by IR sensors aboard viewing satellites, for sanity / sorting checks. These checks typically entail intensity reasonableness tests and rough gating of candidate types considered per region (i.e. whether threat is by land or by sea with ramification on reduced number of classes considered). Using TBO has in the past lucked out due to the requirements being readily met for the tests of boosters largely flying the same paths from the same origins as seen by satellites in fixed posts, with information supplemented by "other assets". In a real worrisome threatening raid (if for example the "FSU"

Figure 8

TYPING

- AN APPLICATION OF HYPOTHESES TESTING
- REQUIRES DETERMINATION OF BEST PROCEDURE
  - DISCRIMINATION RULE
  - COORDINATES USED WITH RULE
- COORDINATES & RULE SHOULD BE CONSISTENT
- COORDINATES ENTAIL
  - FEATURES
  - BLEND
- RULE & COORDINATES BEST IN CONTEXT
  - CRITERION PER PAYOFF DESIRED
  - CONSTRAINTS

Figure 9

CHOICE OF RULE

- MINIMIZE AVERAGE RISK IN CLASS DECISION-MAKING
- DEPENDENT UPON A PRIORI HYPOTHESES COSTS & PROBABILITIES
  - BAYESIAN APPROACH IF KNOWN
    - LEADS TO GENERALIZED LIKELIHOOD RATIO TEST (PER UNEQUAL COVARIANCE MATRICES USED IN QUADRATIC VS CONVENTIONAL LINEAR RULE)
    - ASSUMPTION OF GAUSSIAN STATISTICS OF CLASSES PER EASE / GENERALISM / "COMPATIBILITY"
  - MINIMAX OR NEYMAN-PEARSON ALTERNATIVES FOR DECISION CRITERION IF RESPECTIVELY UNKNOWN PROBABILITIES OR UNKNOWN PROBABILITIES & COSTS

Figure 10

CHOICE OF COORDINATES

- MAXIMIZE SCATTER RATIO MATRIX M = W B
  - WHERE M = WITHIN GROUPS SCATTER (PER COVARIANCE MATRIX OF SIGNATURE DISPERSIONS / UNCERTAINTIES PER CLASS TESTED)
  - B = BETWEEN GROUPS SCATTER (PER OUTER PRODUCT OF DIFFERENCES IN MEANS OF EACH CLASS)
- ADAPT TEST STATISTICS OR OBSERVATIONS TO REAL SITUATIONS (PER APPROPRIATELY FUNCTIONALIZED SIGNATURE DEPENDENCY)
- MAP STATISTICAL MOMENTS TO DECISION HYPERSPACE (FEATURE SPACE FORMATION PROCEDURE?, GAUSSIAN STATISTICS PRESERVED?)
- CONSIDER CANDIDATE OPTIMIZATION CRITERIA FOR FINDING BEST DECISION SPACE (MEANING, COMPARISON)
  - MAX NORM OF M PRE-CONDITIONED AS SYMMETRIC FOR SOLUTION EASE
  - MAX RATIO OF QUADRATIC FORMS IN B & W
  - MAX TRACE OR DETERMINANT, ...?

would de-stabilize) or even for smallish skirmishes, our country and its allies wouldn't necessarily be so fortunate. Thus, Analyticon feels that an enhanced form of booster typing is needed. We have used our expertise to look for this enhancement amongst other largely radiometric typing means. Therefore, in our ongoing investigation we are primarily reliant on radiometric information usage by contrast, but use nonetheless certain information on the booster track in sensor coordinates to suitably transform information, so typing method adaptive to "non-historical" situation, and to "slide" the templates in an automated manner.

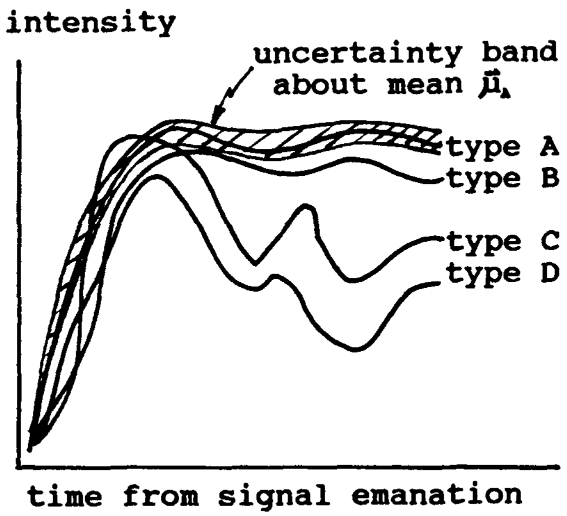
There are, of course, other typing procedures and / or discriminants that have been used or highly touted by the "community" in the past. Accordingly, these include discriminants such as color ratios, staging times, propulsion parameters, and maybe even aspect angle dependency of "stereo pair" intensities. They are, however, especially for the first three mentioned nonetheless often limited due to related key modeling and data issues. Specifically the key procedural alternative, TBO, is as follows:

- o Methodology Used in Operational EW System
  - o TBO: so-called type-by-origin metric method is commonly used throughout IR satellite surveillance / tracking "community" wherein fortuitously / luckily have satisfied typing needs in past by estimating booster launch position sufficiently accurately to correlate launch site with IN supplied information on site contents (and maybe also supplemented by "other assets") - that is really inherently limited to situations that don't entail mobile ICBM / IRBM / SRBM launchers, enemy subs playing tag with each other (per SOSUS barrier and hunter-killer or SLBM type considerations), 2 or 3-party identity quandaries (again noting above caveat and that some of our SLBM boosters conceivably look a lot like some long-range SLBM threats, and there might be an unknown intruder near them that can cause havoc if it launches something and if up-to-date information is not available ops), large mix of types at certain test / SL sites (such as Pl or TT whereby tax ops limit on number of profiles used mono or even for limited / "dual" form of ops stereo used [not to mention if turned off or sick / blinded bird or high Earth central angle for one bird])
- o Methodologies Proposed / Used Herein (see Figures 11 & 12)
  - o Nominal and key variants on proposed baseline method, called herein FLT, that is Fisher-like to generate the best decision space, and is augmented by a general Likelihood Ratio Test (LRT) for decision rule / strategy - whereby accordingly concoct time-dependent input values of the mean and variances of the signature variations due to dispersions and uncertainties say of weather effects, guidance errors, and path influences on observed intensity radiated by booster

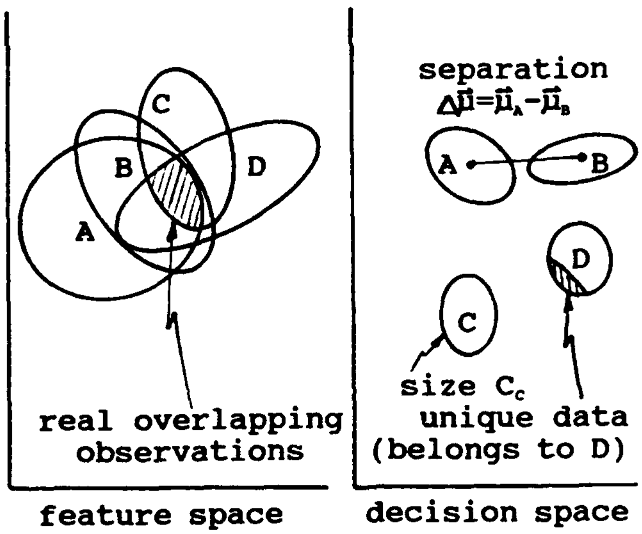
Figure 11
FISHER-LIKE TYPING SPACE DETERMINATION

The proposed / baseline algorithm formulation for pattern recognition consists of determining the best classification space followed by the classification strategy per consistent decision rule (such as LRT). The first step is basically depicted as:

Given Stochastic Patterns of Intensity Signatures (say for 4 booster classes)



Seek Best Decision Space
- o Determined as eigenvectors (eigenvalues indicate payoff)
- o Maximize feature separation & uncertainty / dispersion contour size constriction



In hyperspace representation
- o curved lines map to points
- o ellipsoids if gaussian fuzz

Curves may overlap extensively although not shown for clarity

So SRM* = W^{-1} B $\longrightarrow$ maximum for W= covariance matrix C of fuzz & B= outer product of differenced class means (ensemble averaged over fuzz causes, per within & between groups scatter W & B respectively)

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* so-called scatter ratio matrix of signature matching / pattern recognition theory and associated software tools

Figure 12
Basic Project Procedural Steps

- o Develop Enhanced Booster Typing Methodology
  - o largely radiometrically (with metric aiding)
  - o per firmly grasped analytical foundations
  - o all processing in focal plane coordinates with minimal amount of information but not dependent on launch point
  - o completely integrated software (no loose strings, for formulation and implementation)
  - o compare selected algorithm variants qualitatively
  - o treat salient algorithm formulation / implementation issues (signature clipping, historical to real data mapping, mis-modeling, quadratic vs linear LRT, observation noise, payoff choice, $\geq$2-color data fusion, N class testing, algorithm speed / invariance / amplification)

- o Develop Alternative Algorithm

- o Preliminary Check Using Real IR Satellite Data
  - o properly necessitating a consistent set of sensor measurements (az, el, intensity & time), sensor viewing post location, and trajectory of observed booster
  - o verified initially with representative albeit unofficial signature data and statistical variations per factors such as path, weather & guidance effects
  - o applied striving to solve a key identification problem confronting the surveillance / tracking community - using real / official data
  - o quantify algorithm variants performances & issue resolution

- o Select Algorithm for Final Checkout and Performance Analysis

- o Deliver Associated Detailed Report and User-Friendly Object code of PC software devised / tested

- o Ascertain Interest of Potential Users and Advise on Impact
  - o basis for devising real-time time-urgent typing message for strategic intercept or TMD
  - o refined mission-level booster class / mod information
  - o resolved ID of conventionally often confused boosters
  - o also enhance present typing, assist tracking & BMC^3
- o Seek rapport / sponsorship for Phase II effort continuation

engine (i.e. nominal / depressed / lofted / GEMS as opposed to nominals flown in tests if non-GEMS mode), and then sample monte carlo-wise* from essentially these correlation matrices and mean vectors to map the test statistics to the monte carloed / mapped point values corresponding to W & B respectively (in a suitably formed measurement hyperspace, that isn't seemingly just a conceptual nicety to understand what is really going on in the optimization for the best decision-making coordinates but a required step that could drastically alter the presumed gaussian statistics of the test intensity signatures when mapped to the decision-making coordinates; noting furthermore that the hyperspace consists arbitrarily of the midpoints of the connected albeit canted straight-line segments [≡CSLS] that sufficiently approximate the intensity signature curve in time)

- o Expedient / innovative alternative procedure to FLT (that conceivably provides more timely typing information by testing first and second statistical moments over a judiicious sampling interval)

- o Another alternative not related to FLT (that is also timely but uses another form of data moments to conceivably amplify similar / overlapping data differently, than with a FLT, and without reverting to a "decision hyperspace" with its concomitant eigenvalue problem solution)

- o Other Discriminants

  - o staging times
  - o color ratios
  - o propulsion parameters
  - o stereo aspect influence comparison?, ...

ANALYTICAL DETAILS

For our booster typing baseline algorithm, we have developed the salient related analytical details on the following notions:

- o decision space

  - o criterion of ratio of quadratic forms in W & B

    - o how it can be derived without formal optimization procedure
    - o benefit of said informal derivation

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* albeit alternative available not needing monte carloing but preliminarily elected to monte carlo as part of a user-friendly graphical tool for Phase I that was, per the original technical plan (before revised), used in a "gedanken experiment"

- o formal derivation
- o basic ramifications

- o criterion of pre-conditioned norm of SRM = W^{-1} B
  - o why and how pre-conditioning done
  - o formal derivation
  - o basic ramifications

o decision rule

- o Likelihood Ratio Test generalized in context of also handling disimilar covariance matrices of signature scatter

- o other information (probability of mis-classification, other strategies than LRT)

o factors influencing received (sensed) intensity, with mapping

o transformation from sensor to missile coordinates, useful in mapping historical database to real-time measurement situations or vice versa (choice rationale TBS)

The interested reader is reminded that the Final Report will contain details on the aforementioned analytical information.

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